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HIGH-ALTITUDE OBSERVATIONS

OF AN INTENSE INVERTED-V EVENT

by

C. Y. Huang, L. A. Frank and T. E. Eastman

THE UNIVERSITY OF IOWA
FOUNDED 1847

Department of Physics and Astronomy

THE UNIVERSITY OF IOWA

Iowa City, Iowa   52242

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Abstract

Inverted-V events which generally occur in the pre-midnight sector over the auroral zone are frequently associated with reversals in the convection electric field. Such a reversal is observed by the University of Iowa quadrispherical LEPEDEA on board ISEE-1 at an altitude of 13 R_E on 1 May 1978. The bulk flow of the plasma shows a large shear over a five-minute interval. The associated change in the convection electric field is 5.1 mV m^{-1}. Large values of the field-aligned current are simultaneously detected. The potential structure appears to extend to the satellite location. Using a theoretical model we have calculated the field-aligned current due to the electric field discontinuity. The magnitude of the parallel potential drop and width of the inverted-V region agree well with observation.

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1. Introduction

Intense field-aligned fluxes of precipitating monoenergetic electrons, known as inverted-V events, have long been observed at low altitudes in the auroral regions (Frank and Ackerson, 1971). The main characteristic of such an event is that within a spatially limited region (typically tens to hundreds of kilometers) the average energy of electron precipitation rises and declines sharply, creating the shape of an inverted V on an energy-time spectrogram. It has been shown that the inverted-V events coincide with reversals in the convection electric field in the dawn and dusk sectors (Frank and Gurnett, 1971), however the most intense precipitation is usually observed in the evening and midnight zones (Frank and Ackerson, 1972) where the brightest visual arcs are also seen (Ackerson and Frank, 1972; Craven, private communication, 1983). All the current observational evidence of inverted-V events has come from low-altitude measurements, typically made several hundred to a few thousand kilo-meters above the earth. In this paper we present the first high-altitude observation of an inverted V, gained with the University of Iowa LEPEDEA on ISEE-1 on 1 May 1978 (day 121).

The reversal in the convection electric field is clearly seen, accompanied by strong field-aligned currents. Using a relatively simple model (Lyons, 1980) we can estimate the maximum parallel potential drop along the field lines, the width of the inverted-V region in the ionosphere, and the expected parallel current in such a system. These values agree well with previous observations. There are indications that the potential structure is situated close to the satellite. This unique observation also indicates that the source region for inverted-V events lies within the plasma sheet boundary layer, and not within the central plasma sheet as some authors have suggested

(Lin and Hoffman, 1979). Based on three-dimensional distributions from the LEPEDEA measurements and from the medium-energy particle detector (Williams et al., 1978), the region in which ISEE-1 observes this event is clearly within the plasma sheet boundary layer.

2. Instrumentation

The observations presented here are primarily from the University of Iowa LEPEDEA on board ISEE-1. Samples are taken in 32 passbands in the energy-per-charge range from 1 V to 45 kV. At each energy level 12 azimuthal sectors are covered while 7 polar angles are simultaneously sampled in each azimuthal sector. Thus a full three-dimensional distribution giving 2688 sectors of velocity space is obtained in 128 seconds.

Energy-time (E-t) spectrograms are constructed from these data. An example is shown in Plate 1A for the period 0900 UT to 1500 UT on 1 May 1978 (day 121). This spectrogram displays detector response on the color-coded scale at right. The upper four panels show the detector responses to ion intensities in four solid angle segments near the solar ecliptic plane. From top to bottom these are for ion velocities directed antisunwards, dawnwards, sunwards and duskwards, respectively. The fifth panel shows the electron intensities averaged over all azimuthal sectors, in a plane near the solar ecliptic.

Energy-phase angle (E-ϕ) spectrograms provide details of the velocity distribution in terms of energy versus azimuthal angle for each of the seven polar angles during each instrument cycle. Plates 1B and 1C show examples of such spectrograms. Responses are displayed for each of the seven ion and electron detectors and of the Geiger-Mueller tube. The detectors are numbered 1P through 7P for ions, where the look angles vary from 13° from the space-craft spin axis (1P) through 90° (4P) to 167° (7P). A similar polar range is displayed for the electron channels numbered 1E through 7E. The GM tube responds primarily to high-energy electrons (E $\gtrsim$ 45 keV). The intensity maximum in the solar direction (panel center) is due to solar x-rays. Starting from

the lowest energy level each detector sweeps through all azimuthal angles before stepping up to the next level. Moving from left to right across the azimuthal range displayed in each panel, the velocity directions correspond to particles moving sunward, duskward, antisunward, dawnward and again sunward. For more details the reader is referred to Frank et al. (1978).

3. Observations

On 1 May 1978 both ISEE satellites are situated in the magnetotail ap-
proximately 13 R_E from the earth. Between 1100 UT and 1200 UT ISEE-1 samples
anisotropic distributions which are typical of the plasma sheet boundary
layer. Strong earthward flow centered at several hundred eV is seen in the
third panel of the E-t spectrogram. Simultaneously weaker tailward flow is
recorded and a higher-energy isotropic plasma is present. The electrons are
generally hot and isotropic. At 1200 UT a very large substorm is recorded on
the ground. The AE index rises to ~ 2500 γ, and geomagnetic activity continues
for at least two hours. In the Alberta chain several stations show saturation
between 1200 UT and 1400 UT, with H-component magnitudes in excess of 1000 γ.
The distribution of activity along the chain indicates that the electrojet is
centered at a southerly latitude, as Leduc at 60°N is saturated during most of
this interval (G. Rostoker, private communication, 1983).

The response of the geomagnetic tail to such large disturbances is strik-
ingly seen in the immediate change in the plasma distributions, as seen in
Plate 1A shortly after 1200 UT. The high-energy isotropic component has dis-
appeared, presumably because of contraction of the central plasma sheet, and
highly anisotropic flowing distributions are observed. Plate 1B shows the
distribution from 1200:46 UT to 1202:54 UT, where a tailward-flowing component
at 500 eV has appeared, together with an intense duskward-directed flow at
tens of keV. This anisotropy is also seen at higher energies (Williams, pri-
vate communication, 1983). At this time the ion bulk velocity (in GSM coord-
inates) has components V_x, V_y, V_z equal to 56.9, 150.4, 25.8 km sec^{-1}. When
rotated into a coordinate system aligned along the magnetic field these velo-
cities are seen to be predominantly perpendicular to the magnetic field, with

components $\vec{V}_\perp$ = (88.7, 130.0, 13.6 km sec^{-1}) (see Figure 1, bottom three panels). Thus at this time a large convective electric field exists, primarily in the $-Z_{GSM}$ direction (see Figure 2, panel 3), $|\vec{E}_\perp|$ = 5.7 mV m^{-1}, $E_{\perp z}$ = -5.4 mV m^{-1}. The electron distributions also show distinct anisotropies, most evident seen in panels 3E, 4E, 5E of Plate 1B. However the integrated parallel current density is small, $J_\parallel \approx 6.5 \times 10^{-9}$ A m^{-2}.

The next cycle, shown in Plate 1C, indicates dramatic variations in the plasma distribution. The ion distribution has become intensely beam-like, and the velocity direction has changed. The velocity now has components (189, 8.0, -29.6 km sec^{-1}) which give a perpendicular velocity of $\vec{V}_\perp$ = (189, -5.8, -24.9 km sec^{-1}), i.e., the convective electric field is still large, $|\vec{E}_\perp|$ = 4.3 mV m^{-1}, $E_{\perp z}$ = -4.2 mV m^{-1}. This is partly due to the simultaneous rotation of the magnetic field, which will be discussed later. At this time an intense current is also observed (see panels 3E, 4E of Plate 1C). When this distribution is integrated, excluding photoelectron fluxes seen below 10 eV the net field-aligned current density is 5.4×10^{-8} A m^{-2}. The technique used to obtain the currents is described by Frank et al. (1981). The actual distribution is shown in Figure 4, where contours of equal phase-space density have been plotted relative to the magnetic field direction, such that $V_\parallel$ indicates electrons moving along $\vec{B}$, and $-V_\parallel$ indicates electrons moving antiparallel to $\vec{B}$. It can be seen that the contours are skewed in the direction of $-V_\parallel$, which is the signature of the current directed along $+\vec{B}$. As will be discussed later this flux of field-aligned electrons is precisely the feature which defines an inverted-V event.

Over the following two cycles the plasma velocities decrease, and the corresponding perpendicular electric fields are small ($\lesssim$ 1 mV m^{-1}). Thus in the

interval from 1202:04 UT to 1208:58 UT the z-component of the convective electric field displays a discontinuity of 5.1 mV m^{-1}. During the same interval the field-aligned current density rises to a peak of 5.4 X 10^{-8} A m^{-2}. As we will show, the discontinuity in the perpendicular electric field can be related to an electric field parallel to the magnetic field line, and thus to a parallel potential drop which accelerates electrons into the ionosphere. The velocity distributions of the precipitating particles which constitute the inverted-V event can be directly integrated to give a current density, as we have done. This current density can be compared with the model predictions due to Lyons (1980), and the accelerating potential of the inverted V calculated.

Precisely as the field-aligned current rises to a peak (at 1204:30 UT) the electron thermal energy also maximizes (see Plate 1A). This is also observed on ISEE-2 which is 163 km from ISEE-1, by the fast plasma analyzer (E. Hones, private communication, 1981). In addition the energetic particle detector on ISEE-2 (G. Parks, private communication, 1983) measures a large increase in electron flux in all energy channels; fluxes begin to increase at 1203:50 UT, peak at 1204:32 UT and decrease to their original level at 1205:12 UT. This is shown in Figure 4. (The corresponding times for the rise in temperature observed by the fast plasma analyzer are approximately 1202:31, 1204:17 and 1205:53 UT). The spectral shape is exactly that of a low-altitude inverted-V event. These observations strongly suggest that the acceleration region extends at least to the altitude of ISEE orbit, and probably beyond, during this period of unusual magnetic activity.

Before comparing the observations with theoretical models the unusual magnetic field signatur ¹ser mention. The three components of the

magnetic field are shown in the lower half of Figure 2, where the most striking feature is the large fluctuation in B_x. There are two apparent field reversals, each with an approximate value of ΔB_x of 60 γ, at 1200 and 1204 UT. While both the Mead-Fairfield (1975) and Russell-Brody (1967) models predict that ISEE is close to the neutral sheet at this time the total magnetic field value never drops below 12 γ, and is about 19 γ at the first crossing. The plasma observations show no sign of a typical central plasma sheet, characterized by isotropic ion and electron distributions (see plates 1B, 1C). On the contrary it is clear that the satellite is in a dynamic plasma sheet boundary. Even on smaller time scales than the 128-second cycle of the LEPEDEA the plasma is highly anisotropic with strong gradients (Williams, private communication, 1983). It appears that the central plasma sheet does not exist at this radial distance during this time interval. While such a phenomenon has been reported at larger radial distances from the earth (Cattell and Mozer, 1982) it is highly unusual to observe this extreme thinning at 14 R_E.

A further point to be noted with regard to the magnetic field observations is that at the time when the peak current density is measured by the LEPEDEA, the magnetic field has components (in spacecraft coordinates) 0.75, 19.2, 1.5γ, i.e., the field is almost entirely in the duskward direction. Some minutes before and after this time the field points earthwards, so that the satellite is clearly within the northern hemisphere. We interpret these fluctuations as due to a flapping of the nominal neutral sheet past the spacecraft so that for a time ISEE-1 is on field lines which connect to the southern hemisphere. As the inverted-V event is defined by electrons precipitating into the ionosphere the measured current must be carried by magnetospheric electrons which are accelerated earthwards into the southern hemisphere. We cannot determine

directly whether the electrons ultimately stream earthwards since the observa-

tions simply indicate a dawnward-directed velocity. However the shape of the

distribution function (Figure 5) is strongly suggestive of a magnetospheric

(rather than ionospheric) source for the electron population. Examples of each

type of distribution can be found in Frank et al. (1981). A summary sketch of

the observations is shown in Figure 6.

4. Theoretical Models

We have primarily used the model by Lyons (1980), which in turn uses results due to Atkinson (1970), Knight (1973), Lemaire and Scherer (1974), Chiu and Shultz (1978) and Chiu and Cornwall (1979). This treatment uses the basic condition of a diverging convective electric field ($\nabla \cdot \vec{E} \neq 0$) at an upper boundary to obtain a non-diverging parallel current $J_\parallel$. The theory is based on a steady-state condition, i.e., the electric field is assumed to be time-stationary. Essentially the model is a boundary-value problem, where magneto-spheric conditions at the upper boundary and ionospheric parameters at the lower boundary are supplied. A parallel potential, width of the inverted-V region in the ionosphere and field-aligned current density are predicted.

The electron population, assumed to be Maxwellian of density N and thermal energy K_{th}, incident upon a field-aligned potential drop $V_\parallel$ where the magnetic field has strength B_v causes a current density in the ionosphere (Knight, 1973):

$$J_\parallel = eN \left(\frac{K_{th}}{2\pi m_e} \right)^{1/2} \frac{B_i}{B_v} \left[1 - \left(1 - \frac{B_v}{B_i} \right) \exp \left\{ - \frac{eV_\parallel}{K_{th} \left((B_i/B_v) - 1 \right)} \right\} \right]$$

where B_i = ionospheric magnetic field strength. The current is assumed to non-diverging. Ion contributions which are generally small are ignored.

Following Lyons (1980) under the condition $eV_\parallel/K_{th} \ll B_i/B_v$ which is justified by the observed conditions, the above expression can be written:

$$J_\parallel = eN \left(\frac{K_{th}}{2\pi m_e} \right)^{1/2} \left(1 + \frac{eV_\parallel}{K_{th}} \right)$$

If, in addition, $eV_\parallel/K_{th} \gg 1$, then the field-aligned current density is simply

$$J_\| = \frac{e^2 N}{(2\pi m_e K_{th})^{1/2}} V_\|$$

$$= K V_\| .$$

The half-width of the inverted-V region in the ionosphere is then

$$X_W = \left(\frac{\Sigma_P}{K}\right)^{1/2}$$

where Σ_P = height-integrated Pederson conductivity, assumed to be a constant. The maximum parallel drop is

$$V_{\|M} = \frac{X_W}{2} (E_{1,i} - E_{2,i})$$

where $E_{1,i} - E_{2,i} = \nabla \cdot \vec{E}_i$ is the divergence of the electric field projected along the field lines into the ionosphere.

Applying the conditions for the observations on 1 May 1978,

at 1202:04 UT $E_{\perp z} = -5.4$ mV m^{-1}

at 1208:58 UT $E_{\perp z} = -0.3$ mV m^{-1}

Assuming an ionospheric magnetic field strength of 5×10^4 γ, the divergence of the convective electric field in the ionosphere is

$$|\nabla \cdot \vec{E}_{\perp i}| = 239.8 \text{ mV m}^{-1} \quad (|\vec{B}| \text{ measured at ISEE altitude is } 23\gamma)$$

One difficulty in interpreting the sign of the current due to the electric field discontinuity is the estimate of V_z. To have a current directed out of the ionosphere we must show that $\nabla \cdot \vec{E} < 0$. In our case this means that

V_z must be positive so that the measurement at 1202:04 UT is made above the current sheet, and at 1208:58 UT below the sheet. However the value of V_z calculated from our plasma measurements shows that V_z is small and may change sign in this interval. We have instead used two-satellite estimates of the velocity, using the magnetometers on ISEE-1 and -2. By measuring the time delay between similar features seen at both satellites, and using the separation distance we can calculate a value of V_z. We find that V_z is positive, and approximately 20-30 km s^{-1} in magnitude.

At the time that the current is observed (1204:15 UT) the electron density and thermal energy are 0.5 cm^{-3} and 1.6 keV, respectively. Assuming a value of Σ_p of 40 mhos, in agreement with rocket observations (Evans et al., 1977) the half-width of the inverted-V is then

$$X_w = 357.4 \text{ km,}$$

and the maximum parallel potential drop is:

$$V_{\parallel M} = 42.8 \text{ kV.}$$

This agrees well with observations (Frank and Ackerson, 1971; Lin and Hoffman, 1979). The corresponding maximum parallel current density is

$$J_\parallel = 1.34 \times 10^{-5} \text{ A m}^{-2}.$$

Kinetic simulations yield similar results (Fridman and Lemaire, 1980). When mapped to ISEE location (assuming non-divergence of the current) the predicted current density is 6.0×10^{-9} A m^{-2}. The observed current is 5.4×10^{-8} A m^{-2}, approximately an order of magnitude larger than the theoretical value. The discrepancy may be due to the simple assumptions made in applying the model, e.g.,

a constant value of $\sum_p$. In addition the model does not take into account (1) particles which reflect before reaching the potential structure, (2) particles which reflect within the potential structure, and (3) backscattering from the ionosphere. In our case the parallel potential appears to extend over some distance, with ISEE situated within the endpoints of the structure. The electrons which carry the current have already been accelerated when the observations are made. Thus for the prevailing conditions a kinetic simulation would probably yield better agreement. However this simple theoretical approach predicts results which compare very favorably with the observations.

A simple calculation can be made to predict an upper limit to the current density, using the observed details of the electron distribution function. If we assume a loss cone of 1° at the ISEE location (geocentric distance of 14 R_E), and assume also that the potential drop is located near the spacecraft (so that no particles mirror before being accelerated) we can estimate the number of particles lost through the loss cone and hence the current density at low altitudes.

The parallel potential is approximately 34 kV, thermal energy and density of the incident population are 1.6 keV and 0.5 cm^{-3}, respectively. If we assume that the incident population is isotropic, the current density due to this accelerating potential is 1.13×10^{-6} A m^{-2}. If the electrons have a field-aligned distribution which is more likely the current density is increased considerably to $\sim 1 \times 10^{-5}$ A m^{-2}. The observed current density of 5.4×10^{-8} A m^{-2} is well below this upper limit. This calculation again suggests that the potential drop occurs over some distance so that some electrons are mirrored before they can be accelerated through the full potential.

High-altitude inverted-V regions have been predicted by low-altitude mea-
surements, in which the pitch-angle distributions of precipitated electrons
have been examined (Lin and Hoffman, 1979; Mizera et al., 1976; Hoffman and
Evans, 1968). The maximum pitch angle of precipitating particles accelerated
by a static electric field should be $\alpha_M = \sin^{-1} (K_{th}/(K_{th} + eV))^{1/2}$, where the
distance between the observation point and the electric field is assumed to be
small. In many cases the observed pitch-angle distribution extends to much
higher angles, indicating that the acceleration region is distant from the
satellite, so that conservation of the first adiabatic invariant leads to
large pitch angles. Alternately wave-particle interactions could produce a
spreading of the precipitated flux, although this has not been investigated.

The parameters we have used in our model calculations are generally
reasonable. We have not attempted a full solution of the current continuity
equation, in which the conductivity and parallel potential drop are related to
the energy flux of the precipitating particles. However we would expect to
see only refinements of the basic results presented here.

One problem in comparing the predicted results with observations lies in
the spatial scale of the inverted-V region. In the idealized case treated by
Lyons (1980) the electric field is discontinous in an infinitely small region,
while the current flows within the full width of the inverted-V. In our case
the width is predicted to be approximately 700 km. When mapped to ISEE posi-
tion this becomes a current sheet of thickness ~ 5 R_E. The measured thick-
ness, estimated from the magnetic field deflection and observed current den-
sity is 1037 km, which corresponds to an ionospheric inverted-V precipitation
region of 22 km. This large discrepancy between observed and predicted spat-
ial scales is partly resolved when the actual structure of the magnetospheric

electric fields are considered (Lyons, 1981). It appears that the large current density observed by ISEE corresponds to a bright auroral arc, but that this is embedded within a spatially larger precipitation region characterized by an overall diverging electric field.

5. Conclusions

Observations made with the LEPEDEA on board ISEE-1 indicate that an intense inverted-V event occurs on 1 May 1978. These observations are unique in that they are made with a high-altitude satellite situated at 13 R_E from the earth at this time. The geomagnetic conditions for this event are highly unusual - on the ground a large substorm is recorded, while at the ISEE orbit the central plasma sheet appears to have disappeared. These circumstances may be the reasons that this spectacular event is observable at high altitudes. The convective electric field is discontinuous shortly after 1202 UT, due to large shears in the plasma flows. Associated with this discontinuity strong currents are observed flowing out of the ionosphere, and the electron spectra show a rapid increase in energy, peaking in the center of the electric field discontinuity and declining shortly afterwards. This signature, characteristic of an inverted-V event, suggests strongly that the field-aligned potential extends to an altitude $\gtrsim$ 13 R_E, well above the heights of 2-2.5 R_E usually quoted (Ghielmetti et al., 1978). The plasma distributions measured by the LEPEDEA and the medium-energy particle detector show that throughout the interval we are situated in the plasma sheet boundary layer. The magnetic field signatures suggest that for a time field lines which connect to the southern hemisphere cross the satellite. At the time when this occurs the field-aligned current is measured, so that the inverted-V region maps to the ionosphere south of the magnetic equator. Before and after the event the satellite is on field lines which connect to the northern hemisphere.

We have used a model due to Lyons (1980) which predicts the parallel potential drop, width of the inverted-V in the ionosphere and the parallel current density due to the field-aligned potential. The values obtained

agree well with observations. The current computed density can be mapped from the ionosphere to ISEE location, assuming that the decrease in the current density is due only to divergence of the field lines. The predicted and observed current densities at ISEE location are in good agreement. The limitations of the theory do not allow for calculation of the size scale of smaller-scale areas within the precipitation region. However we believe these difficulties to be minor relative to the overall success in predicting the gross features most characteristic of inverted-V events. The agreement, both quantitative and qualitative, is remarkably good.

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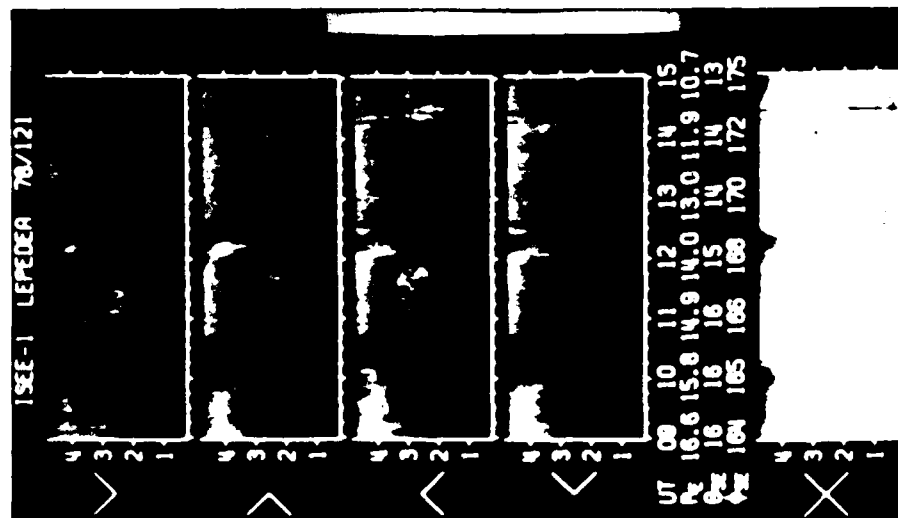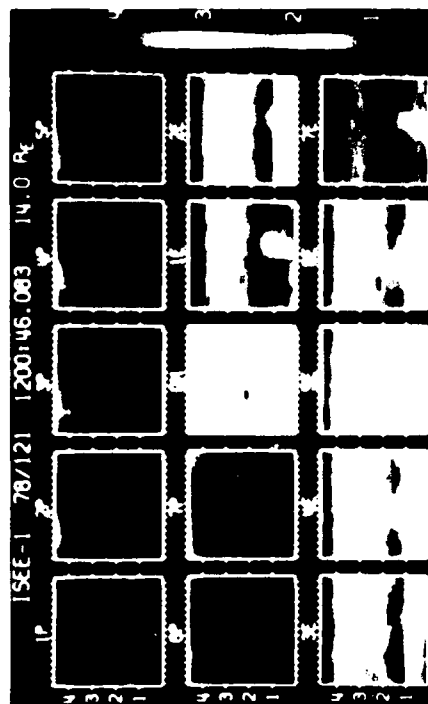   Electron., 16, 270, 1978.

Plate Caption

Plate 1.
(a) E-t spectrogram showing the detector responses on
1 May 1978.

(b) E-ϕ spectrogram showing strong duskward flow at high
energies panels 2P, 3P, 4P, 5P. Electron anisotropies
are also present at 1 keV.

(c) Intense electron anisotropies can be seen at 2 keV in
panels 3E, 4E, 5E. This corresponds to a large field-
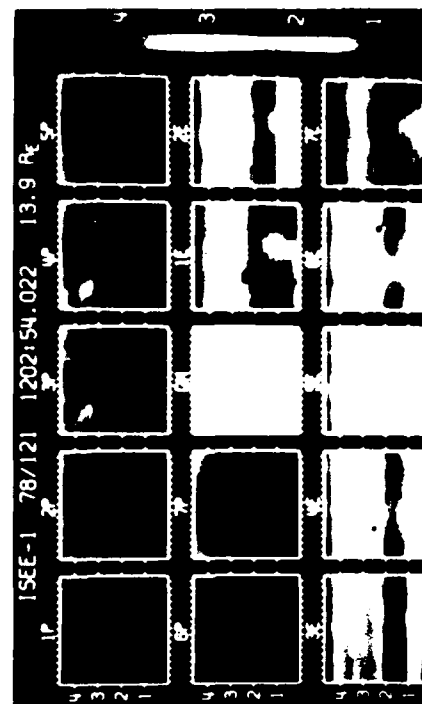aligned current.

Figure Captions

Figure 1.   The thermal energy and velocity of the bulk ion distribution are shown for 1 May 1978. Large shears in $V_{\perp x}$ and $V_{\perp y}$ can be seen shortly after 1200 UT.

Figure 2.   The three components of the convective electric field are shown in the top three panels. The large discontinuity in $E_{\perp z}$ is indicated. The magnetic field components are shown in the lower three panels.

Figure 3.   The parallel and perpendicular components of the ion velocity are plotted, where points 1 and 2 correspond to the electric field discontinuity in Figure 3. The magnetic field and observed current density are also shown. The peak current density of 5.4×10^{-8} A m^{-2} is observed at 1204:15 UT.

Figure 4.   Electron fluxes at 2 keV, 6 keV and 8 keV are shown for the period 1150 UT to 1220 UT on 1 May 1978. these are observed with the energetic particle detector on ISEE-2 (G. Parks, Private communication, 1983). The peak in the flux at 1204:32 is clearly seen in all channels.

Figure 5.   The electron distribution at 1204 UT is plotted in velocity space relative to the magnetic field direction. The contours of equal phase space density are clearly shifted towards $-V_{\parallel}$, corresponding to a current directed along $+\vec{B}$.

Figure 6.   The relative positions of ISEE-1 and the inverted-V region are shown in this schematic diagram. The magnetic field and plasma velocity are indicated at the two end points of the discontinuity in the electric field.
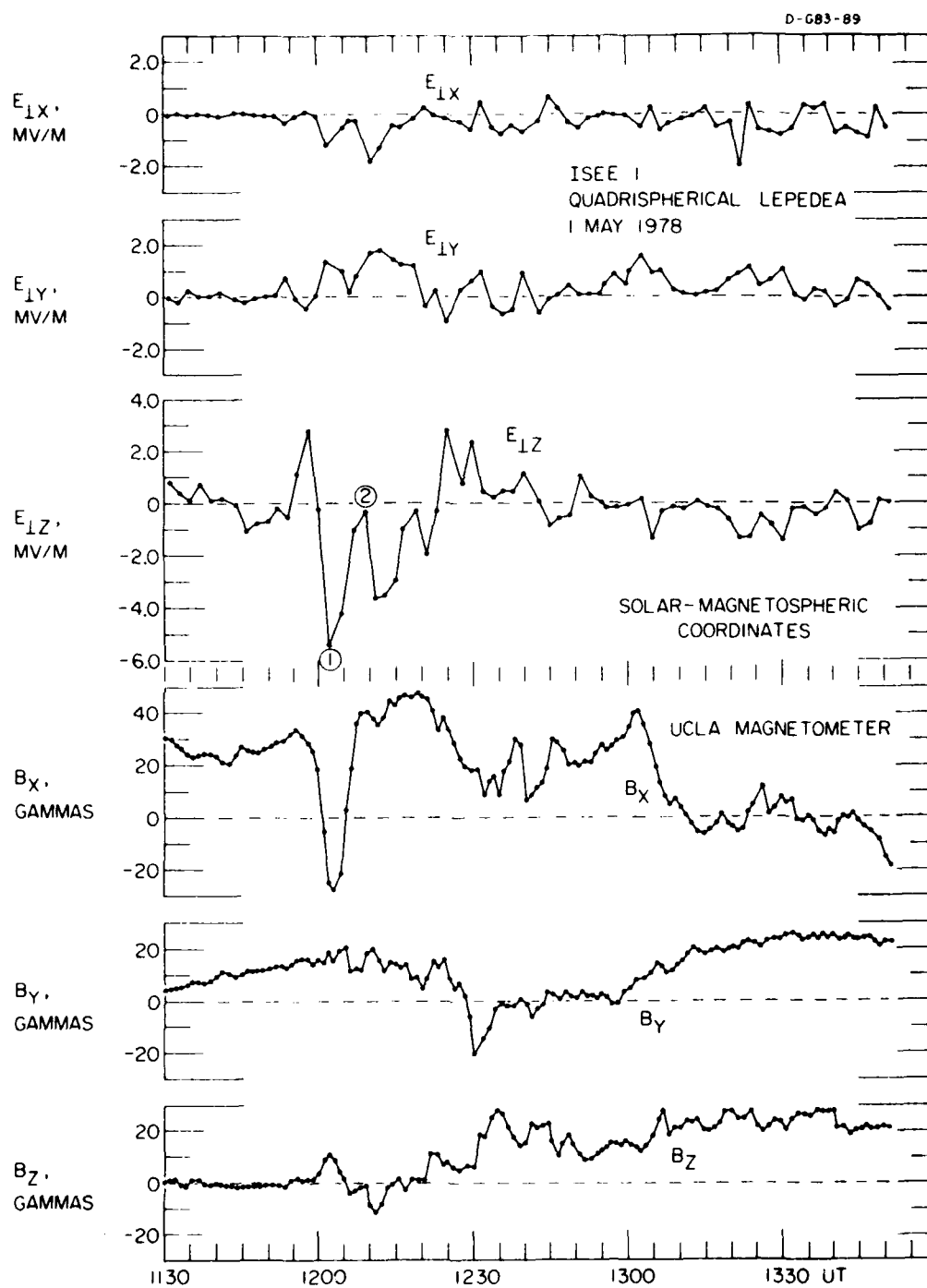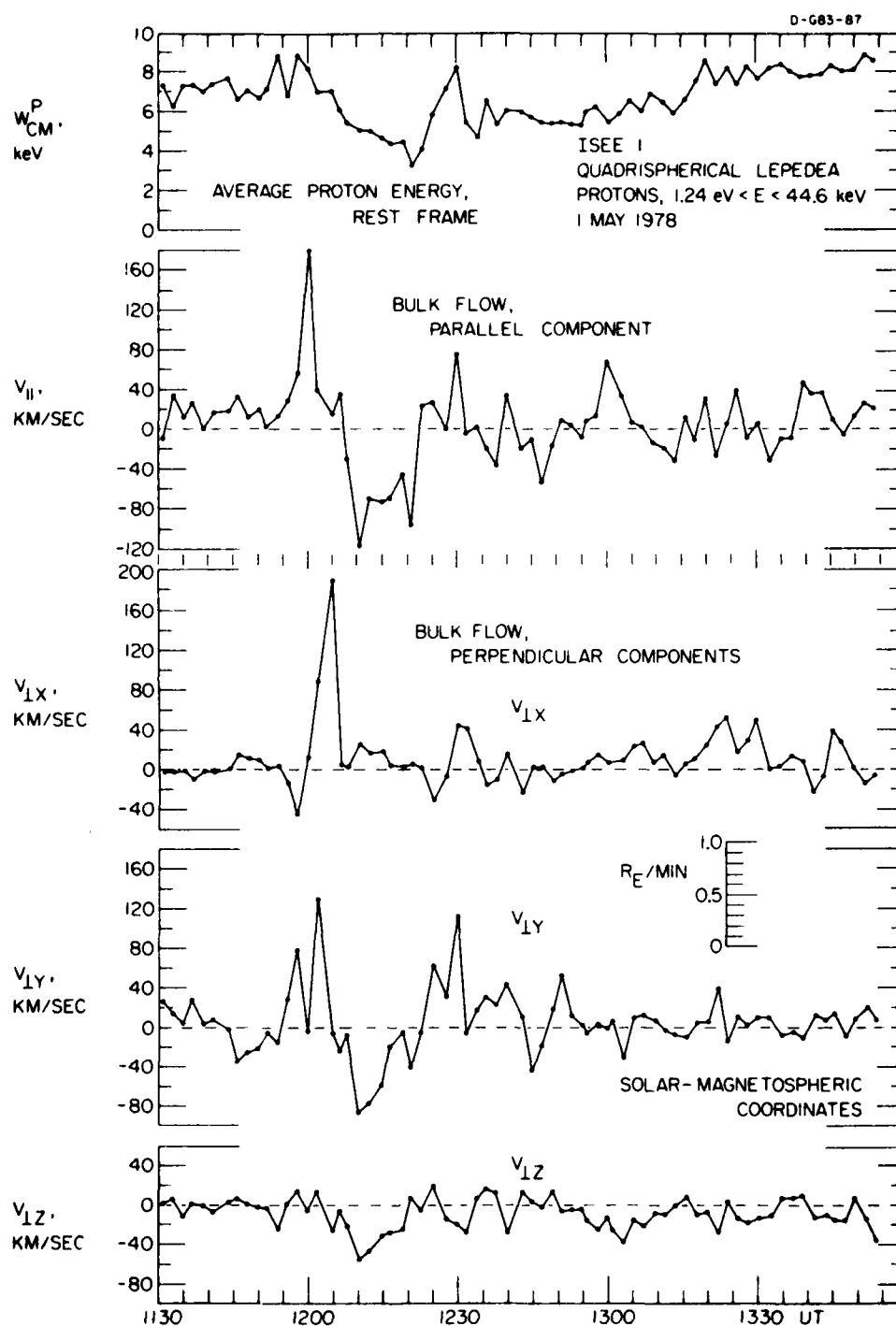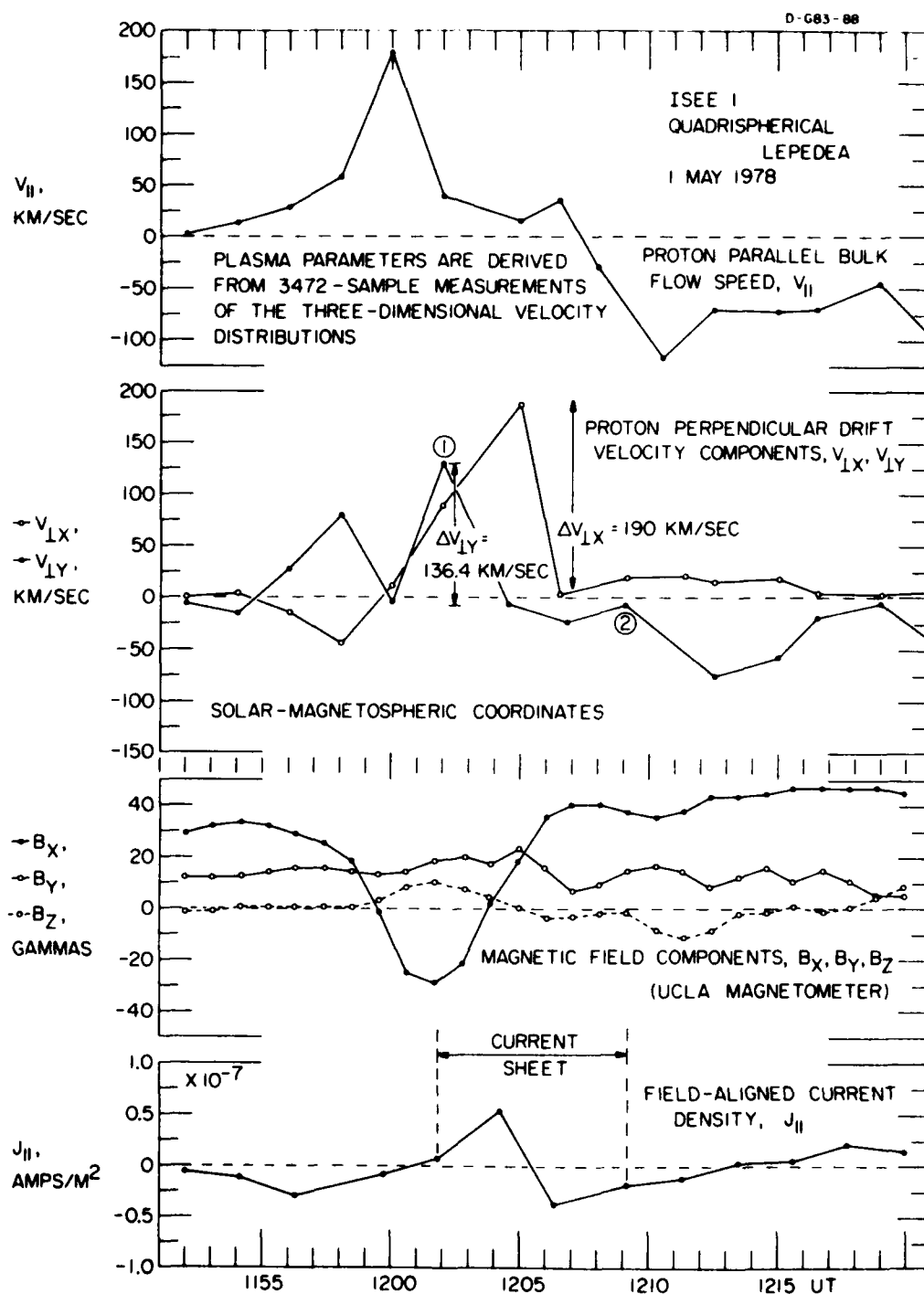
Plate 1

Figure 1

D-G83-87

Figure 2

Figure 3

A-G83-223

Figure 4

C-G83-101-1

ISEE-1
1 MAY 1978 (DAY 121)
1204 UT
ELECTRON DISTRIBUTION
        FUNCTION

CONTOURS OF
EQUAL PHASE-SPACE
DENSITY, $f(V_{||}, V_\perp)$, IN UNITS
OF $CM^{-6} SEC^3$

— — — REFERENCE, ISOTROPY
WITH NO BULK FLOW

FIELD-ALIGNED CURRENT DENSITY
$= 5.4 \times 10^{-8}$ AMP M^{-2}

Figure 5

C-G80-961-4

$\vec{B}$

① ②

$\vec{J}_{\parallel}$

~7000 KM

$V_{\perp Y} =$ −6 KM/SEC

$V_{\perp X} =$ 2.4 KM/SEC

① $E_{\perp Z} =$ −5.4 mV/M

② $E_{\perp Z} =$ −0.3 mV/M

$J_{\parallel} = 5.4 \times 10^{-8}$ AMP/M²

INTERPRETIVE SKETCH —
ISEE CROSSING OF FIELD−ALIGNED CURRENT
AND ASSOCIATED CONVECTION ZONES

ISEE−1 POSITION: $\vec{X}_{SM}$ (−13.2, 2.1, 3.9 R_E)
1204 UT
1 MAY 1978

$V_{\perp Y} =$ 130 KM/SEC

$V_{\perp X} =$ 189 KM/SEC

N

S

$\Delta \lambda \simeq 0.7°$
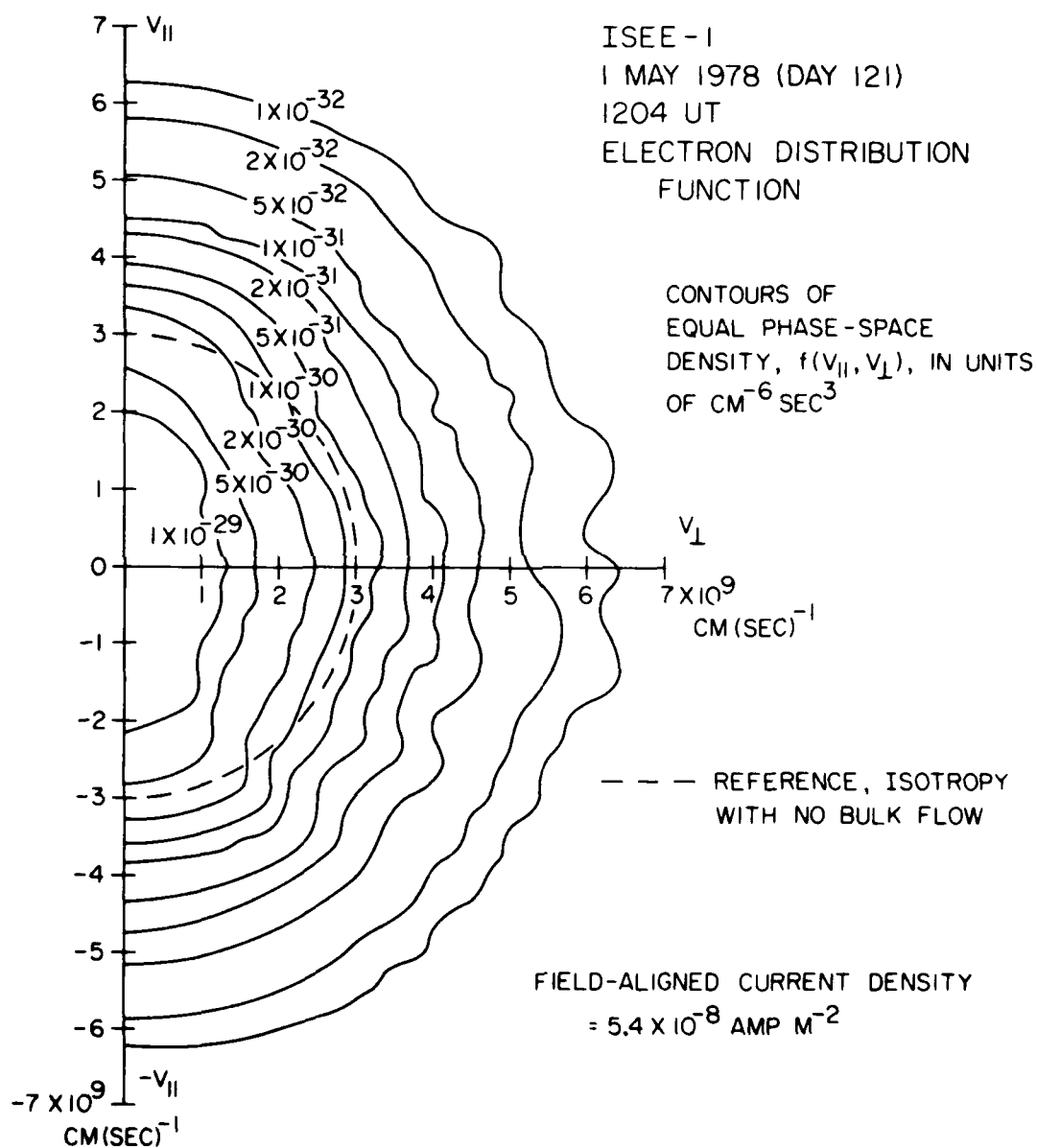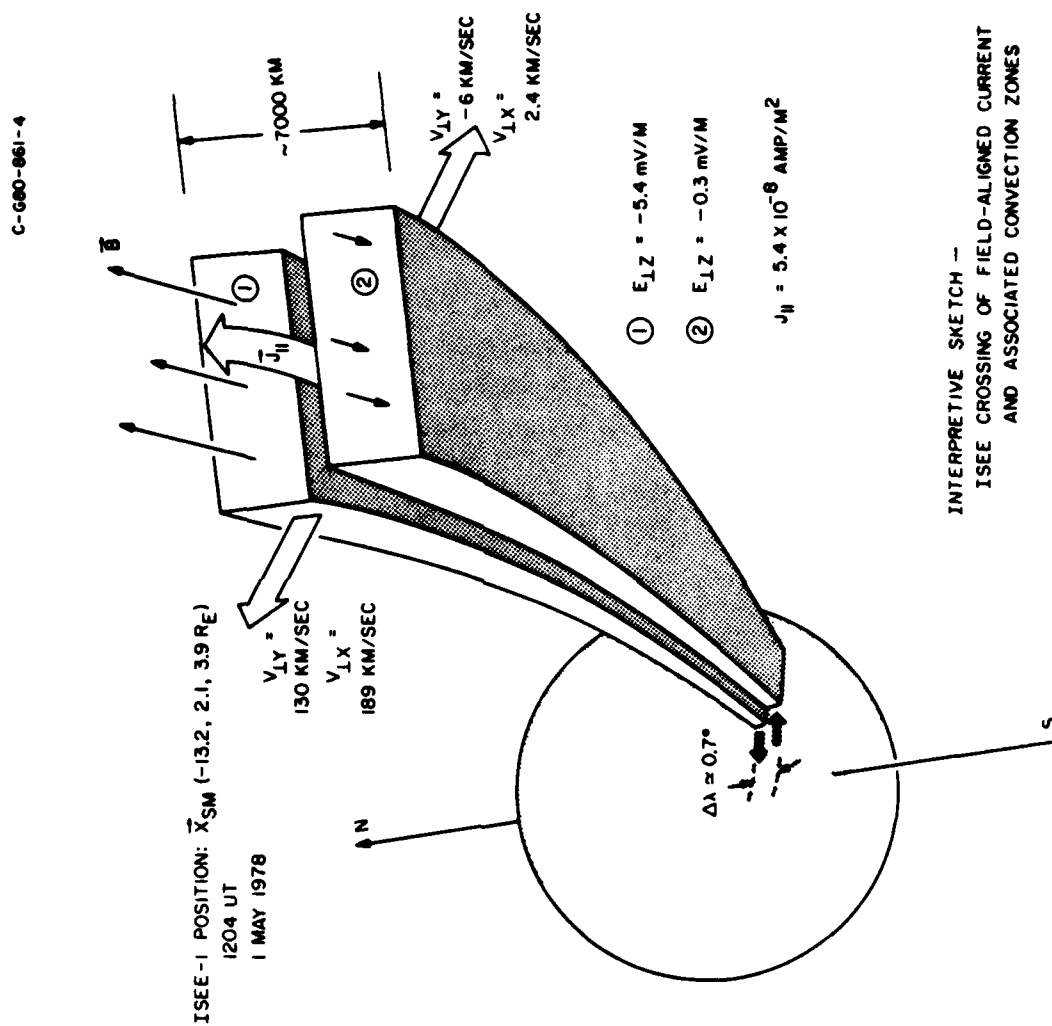
Figure 6

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Inverted-V events which generally occur in the pre-midnight sector over the auroral zone are frequently associated with reversals in the convection electric field. Such a reversal is observed by the University of Iowa quadrispherical LEPEDEA on board ISEE-1 at an altitude of 13 R_E on 1 May 1978. The bulk flow of the plasma shows a large shear over a five-minute interval. The associated change in the convection electric field is 5.1 mV m^{-1}. Large values of the field-aligned current are simultaneously detected. The potential structure appears to extend to the satellite location. Using a theoretical model we have calculated the field-aligned current due to the electric field discontinuity. The magnitude of the parallel potential drop and width of the inverted-V region agree well with observation.

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